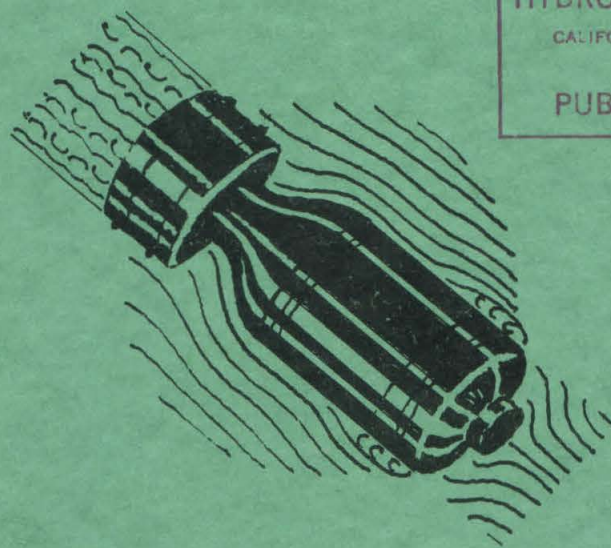


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DIVISION SIX-SECTION 6.1

WATER TUNNEL TESTS  
OF THE  
M-6, 2.36" A.T. ROCKET  
WITH FIVE DESIGNS OF SHROUD TAIL



HYDRODYNAMICS LABORATORY  
CALIFORNIA INSTITUTE OF TECHNOLOGY  
PASADENA  
PUBLICATION NO. 50

THE HIGH SPEED WATER TUNNEL  
CALIFORNIA INSTITUTE OF TECHNOLOGY  
PASADENA, CALIFORNIA.

SECTION No 6.1-Sr-207-934  
HML REP No. ND-11.5  
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DIVISION SIX -- SECTION 6.1

MEMORANDUM ON WATER TUNNEL TESTS OF THE  
M-6, 2.36" A. T. ROCKET  
WITH FIVE DESIGNS OF SHROUD RING TAIL

BY

ROBERT T. KNAPP  
OFFICIAL INVESTIGATOR

THE HIGH SPEED WATER TUNNEL  
AT THE  
CALIFORNIA INSTITUTE OF TECHNOLOGY  
HYDRAULIC MACHINERY LABORATORY  
PASADENA, CALIFORNIA



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### ABSTRACT

This report covers tests on the M-6, 2.36" rocket with the conical pointed nose in combination with an experimental shroud ring tail from the Aberdeen Ballistic Research Laboratory; also with a commercially manufactured Ordnance Department shroud ring tail; and with three types of specially made model tails on which the shroud length was varied. One of the specially made model tails was mounted on a plain boom with no nozzle. All of the other tails were mounted on a stepped venturi nozzle.

### CONCLUSIONS

The shroud ring tail (Tail No. 47) without the nozzle reduces the drag materially and increases the static stability. The increase in stability is due almost entirely to the shift of the center of gravity toward the nose due to dropping the weight of the nozzle, while the location of the center of pressure is shifted aft only slightly.

The Aberdeen experimental tail, with three supporting fins (Tail No. 59), shows less drag and higher static stability than the Ordnance Department tail which has four fins (Tail No. 58).

These two tails (Nos. 58 and 59) are substantially constructed and appear well adapted to rough handling, especially Tail No. 59. The specially made model tails, on the other hand, Tails Nos. 34 to 35, 36 to 40, and 47 to 51 appear too fragile for ordinary handling and shipping. Modification of these tails to make them more substantial would slightly increase the drag but the added weight in the tail would not reduce the stabilizing moment more than about 10%.

A shroud length of 80% of the shroud diameter shows higher stability than longer or shorter shrouds in the case of the specially made tails mounted on the stepped nozzle (Tails Nos 34-35 and 36-40). From these results it can be concluded that the stability with the two commercially made tails (Tails Nos. 58 and 59) could be improved by shortening the shroud length. For the tails mounted directly on the boom (Tails Nos. 47-51) a shroud length 80% of the diameter shows only slightly less stability but considerably less drag than a shroud of length equal to the diameter.

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1. PURPOSE

The purpose of this report is to compare the hydrodynamic characteristics of the 2.36" A.T. Rocket with the five different shroud ring tails described in detail in Section 2 following: also, to investigate the effect of varying the length of the shroud and to compare the results of tests with and without a nozzle.

2. DESCRIPTION OF MODELS TESTED

All tests were made on full-scale models. The RT 5-15-43 Mk 2 tail and the Ordnance Department tail were tested as received. All test assemblies were made up with the conical pointed nose (Nose No. 8).

The RT 5-15-43 Mk 2 tail was submitted to the Laboratory by Dr. David R. Webster from the Ballistic Research Laboratory at Aberdeen. Preliminary test results were reported to Dr. Webster by letter of September 25, 1943. It is designated in this report as Tail No. 59. Figure 1 is a photograph of the model with this tail. Figures 2 and 3 show the tail in more detail, and Figure 31 is a scale drawing of the tail as received. It consists of a shroud 2.35" in diameter and 2-4/16" long, mounted on three channel section supporting fins. The fins are stepped to fit the three steps on the nozzle. The forward edge of the shroud ring is 1/4" forward of the end of the nozzle.



FIGURE 1  
ROCKET WITH TAIL No. 59  
(ABERDEEN RT 5-15-43 Mk 2 TAIL)

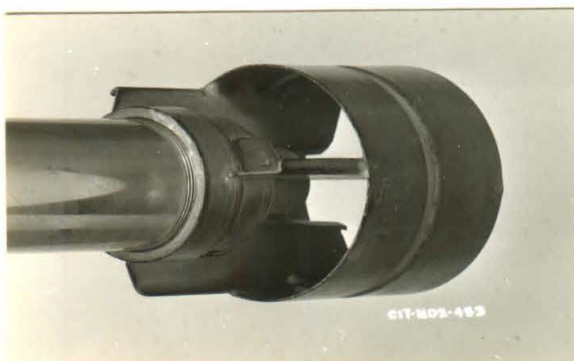


FIGURE 2



FIGURE 3

TAIL No. 59



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The commercially manufactured tail is referred to in this report as Tail No. 58. It was submitted to the Laboratory by Capt. E. G. Uhl of the Army Ordnance Department and the test results given herein were reported to him in a memorandum from R. T. Knapp on August 9, 1943. Figures 4 and 5 show the detail views of this tail and Figure 32 is a scale drawing of the tail as received. This tail has four supporting fins. It is made up of four identical stampings, each including one fin and one quadrant of the shroud ring. The shroud ring is 2.30 inches in diameter and 2.34 inches long. The forward edge of the shroud is 0.69 inches forward of the end of the nozzle. Each of the fins is flanged for attachment to the intermediate step of the nozzle.



FIGURE 4

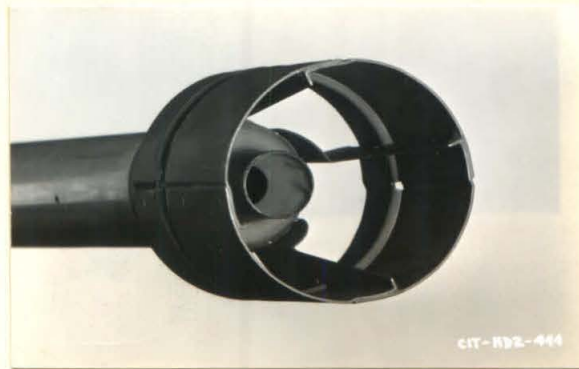


FIGURE 5

TAIL No. 58  
(ORDNANCE DEPARTMENT TAIL)

Tail No. 36 is a specially made model tail. It is quite similar to Tail No. 59, but is more smoothly made, the flanges of the supporting fins are narrower and do not extend aft of the end of the nozzle. The forward edge of the shroud is  $7/16$  inch forward of the end of the nozzle and the shroud of Tail No. 36 is  $2-3/8$  inches long. Tails Nos. 37 to 40 were made by successively cutting off short lengths from the after end of the shroud of Tail No. 36. Figures 6 and 7 are photographs of Tail No. 38. Figure 34 is the detail drawing from which the tail was made, and shows the shroud lengths of Tails Nos. 36 to 40.

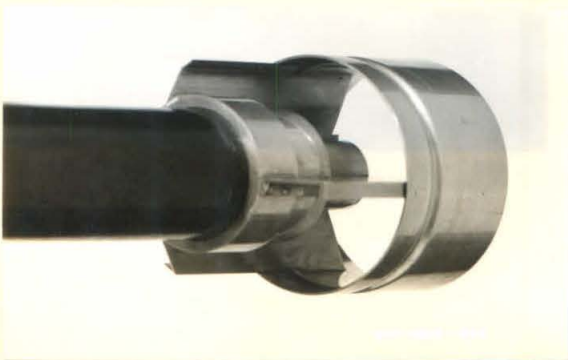


FIGURE 6



FIGURE 7

TAIL No. 38

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Tail No. 34 is also a specially made model tail. It differs from Tail No. 36 in that the fins are attached only to the largest diameter of the nozzle and are not stepped to fit the smaller nozzle diameter. Tails Nos. 32 to 35 were made by cutting off short lengths from the after end of the shroud of Tail No. 34. Figures 8 and 9 show detail views of Tail No. 35 and Figure 33 is the detail drawing from which Tails Nos. 34 to 35 were made.



FIGURE 8



FIGURE 9

TAIL NO. 35

Tails Nos. 47 to 54 are all of the same construction, differing only in length of shroud. Figures 10 and 11 show the construction and Figure 35 is a detail drawing from which the model was made. The shroud ring is supported on three fins of channel section attached directly to the boom. There is no nozzle. The shroud ring on Tail No. 47 is 2-3/8" long and the forward edge of the shroud is 4-1/8" aft of the end of the boom. Tails Nos. 48 to 54 were made by successively cutting off short lengths from the after end of the shroud ring of Tail No. 47.



FIGURE 10

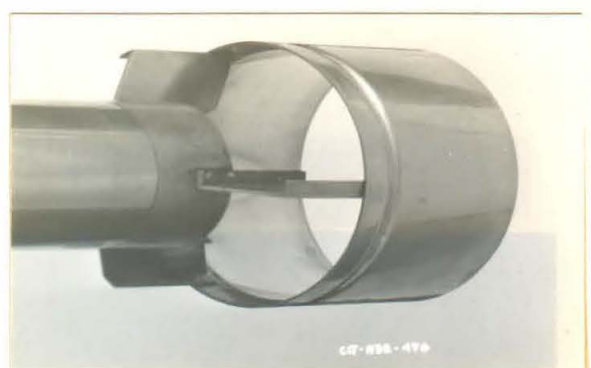
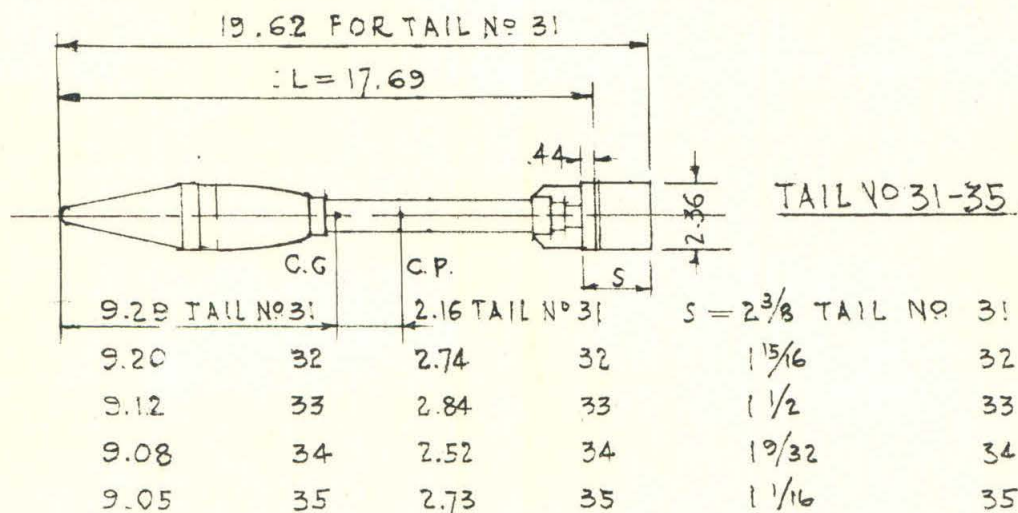
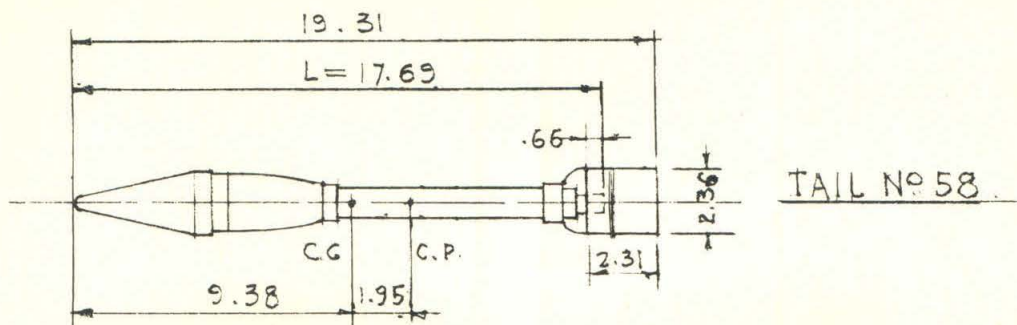
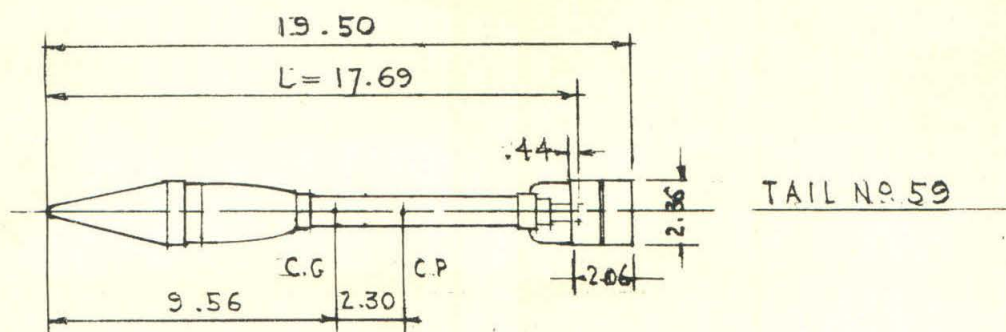


FIGURE 11

TAIL NO. 47

Figures 12 and 13 show diagrammatic scale drawings of all models covered by this report, giving the principal dimensions and the location of the center of gravity and center of pressure.

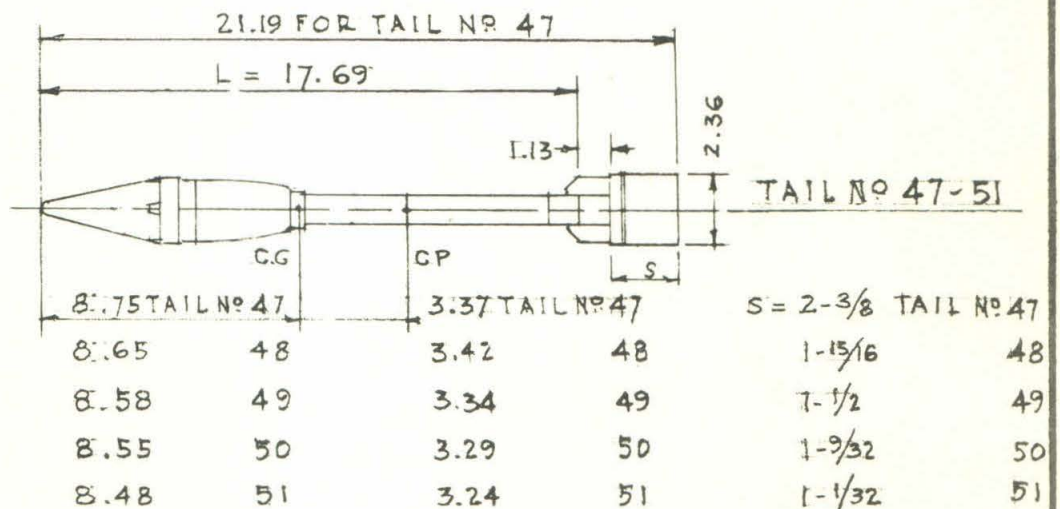
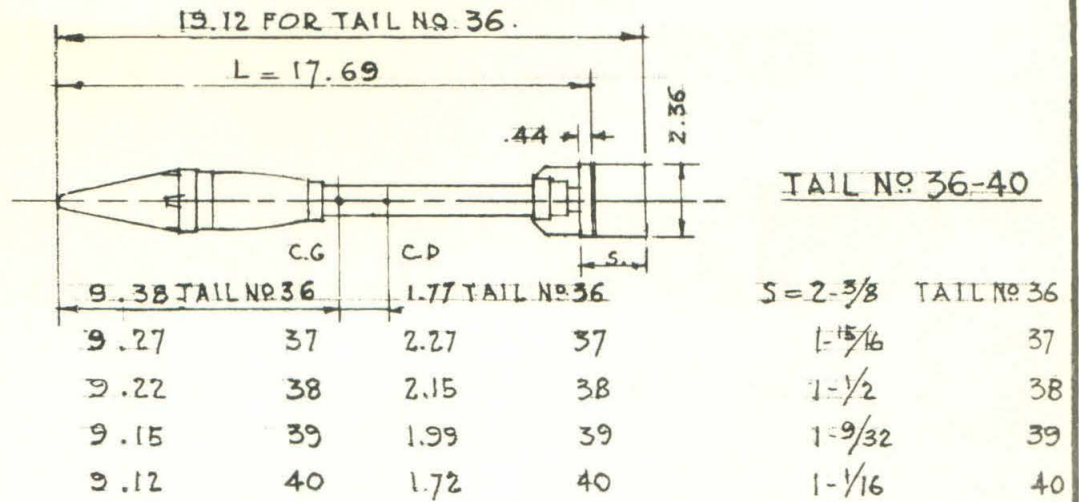




ALL C. P. LOCATIONS ARE FOR 4° YAW

HYDRAULIC MACHINERY LABORATORY CALIFORNIA INSTITUTE OF TECHNOLOGY		
DR E.D.R 10/27/43	2.36 ROCKET PROJECTILE	SCALE
CH	COMPARISON OF PROFILE DIMENSIONS	ND11-1683L
AP	AND C.G. AND C.P. LOCATIONS	

FIG. 12.



ALL C.P. LOCATIONS ARE FOR 4° YAW

HYDRAULIC MACHINERY LABORATORY		CALIFORNIA INSTITUTE OF TECHNOLOGY	
DR E.D.R. 10/27/43	2.36 ROCKET - PROJECTILE COMPARISON OF PROFILE DIMENSIONS AND C.G. AND C.P. LOCATIONS.		SCALE
CH			ND11-1684L-T
AP			

FIG. 13.

## 3. FORCE MEASUREMENTS

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Determination of drag, cross force, and moment were made by tests in the High Speed Water Tunnel. The principal force coefficients, calculated from the observed forces, are summarized in the following tabulation, and shown graphically on Figure 14:

Note:

All tests made with conical pointed nose (Nose No. 8)

Coefficients calculated from averaged, faired force observations. *Length taken from point of nose to end of nozzle.*

RUN NO.	TAIL NO.	SHROUD LENGTH INCHES	L	Length of model, inches (point of nose to end of nozzle)		Drag coefficient at zero yaw		Cross force coefficient at 4 degrees yaw		Moment coefficient (about center of gravity) at 4 degrees yaw		Distance from nose to center of gravity, relative to length		Center-of-pressure eccentricity (= distance from C.P. to C.G. relative to length) at 4 degrees yaw	
				C <sub>D</sub>		C <sub>C</sub>		-C <sub>M</sub>		e					
92, 99															
100, 101	59	2-1/16	17.7	0.32	0.22	0.033	0.54	0.13							
87	58	2.31	17.7	0.43	0.20	0.027	0.53	0.11							
39, 42	31	2-3/8	17.7	0.37	0.20	0.028	0.53	0.12							
46	32	1-15/16	17.7	0.37	0.19	0.034	0.52	0.16							
47	33	1-1/2	17.7	0.36	0.18	0.033	0.52	0.16							
48	34	1-9/32	17.7	0.35	0.18	0.029	0.52	0.14							
49	35	1-1/16	17.7	0.35	0.17	0.019	0.51	0.10							
52, 57, 58, 59	36	2-3/8	17.7	0.37	0.20	0.022	0.53	0.10							
72	37	1-15/16	17.7	0.37	0.18	0.030	0.52	0.15							
75	38	1-1/2	17.7	0.37	0.19	0.026	0.52	0.12							
77	39	1-9/32	17.7	0.36	0.19	0.024	0.52	0.11							
78, 83	40	1-1/16	17.7	0.35	0.19	0.021	0.51	0.10							
91	47	2-3/8	16.7	0.28	0.22	0.049	0.52	0.20							
96	48	1-15/16	16.7	0.22	0.22	0.048	0.52	0.20							
97	49	1-1/2	16.7	0.21	0.21	0.046	0.51	0.20							
98	50	1-5/16	16.7	0.21	0.21	0.045	0.51	0.20							
107	51	1-1/32	16.7	0.20	0.21	0.043	0.51	0.19							

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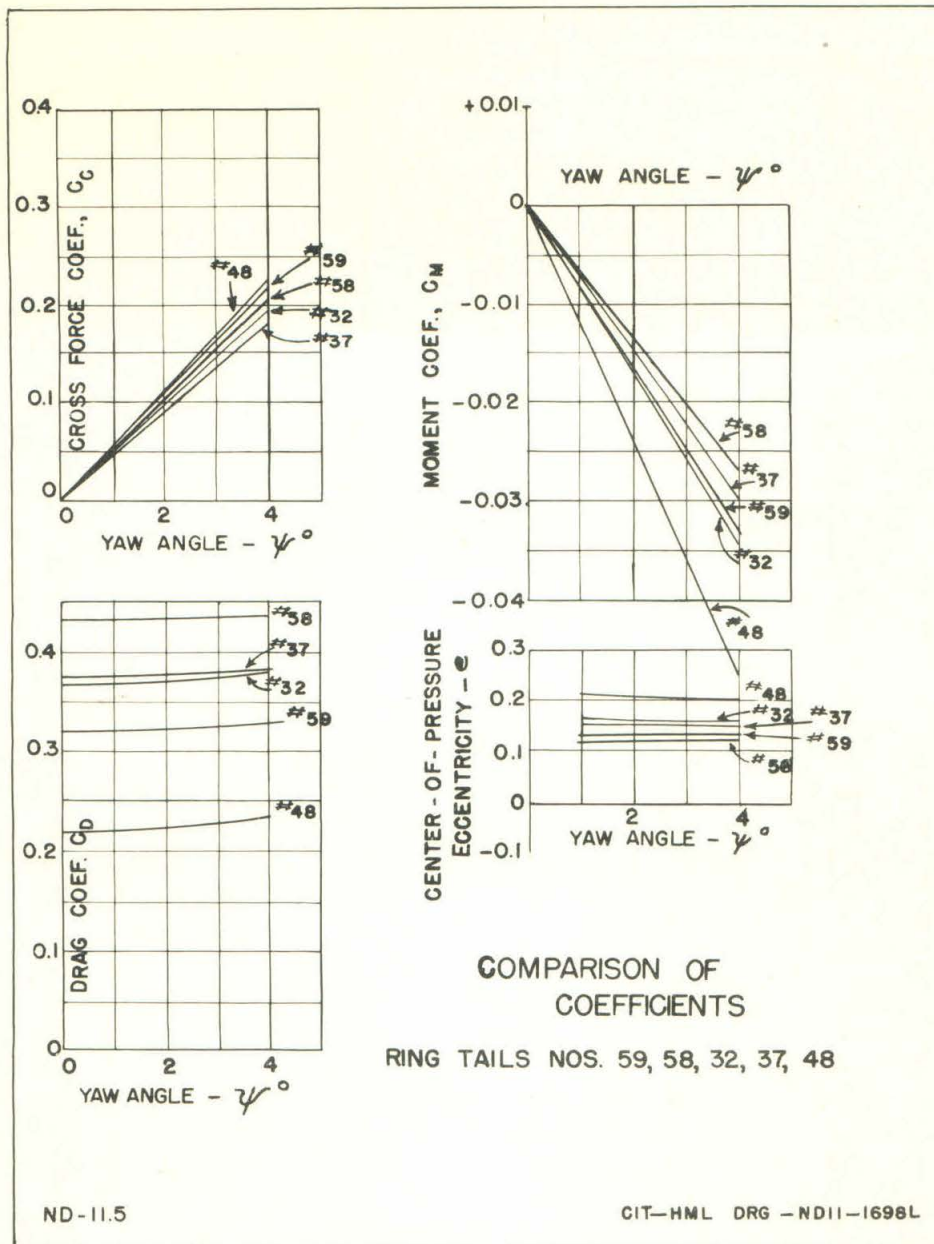


FIG. 14

It is to be noted that Tail No. 59 gives less drag and greater static stability than Tail No. 58. Tails in the 47-51 series (no nozzle on end of boom) show greater stability and less drag than any of the others. The increase in stability appears, from consideration of the force coefficients, to be due mainly to a forward shift of the center of gravity. For example, the relative increase in restoring moment of Tail No. 48 over Tail No. 59 is approximately the same as the relative increase in center-of-pressure eccentricity.

The curves on Figure 14 show that for each model the slope of the moment curve is constant up to a yaw angle of four degrees. The curves of center-of-pressure eccentricity show a nearly uniform value of  $e$  for each model as the yaw angle is increased. The drag on all models increases only slightly with increased yaw.

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In all previous reports and memoranda relating to the 2.36" A. T. Rocket, the calculation of moment coefficient,  $C_M$ , and the location of the center of pressure and center of gravity relative to the projectile length have been made using a length of 24.38 inches, which was the overall length from tip of nose to tip of tail of the first 2.36" rocket submitted to the laboratory and covered by Report No. ND-11, November 19, 1942. This particular length has no correlation with the dimensions of most of the 2.36" rocket models now being investigated and its general use is now discontinued. The length dimension used in this report is the actual length from the front end of the projectile nose to the after end of the nozzle tip. This dimension varies somewhat on different designs of the 2.36" rocket, but for any given design of nose, afterbody, and propellant chamber, it appears to be the most logical dimension to use in comparing the effect of different tails on the static stability.

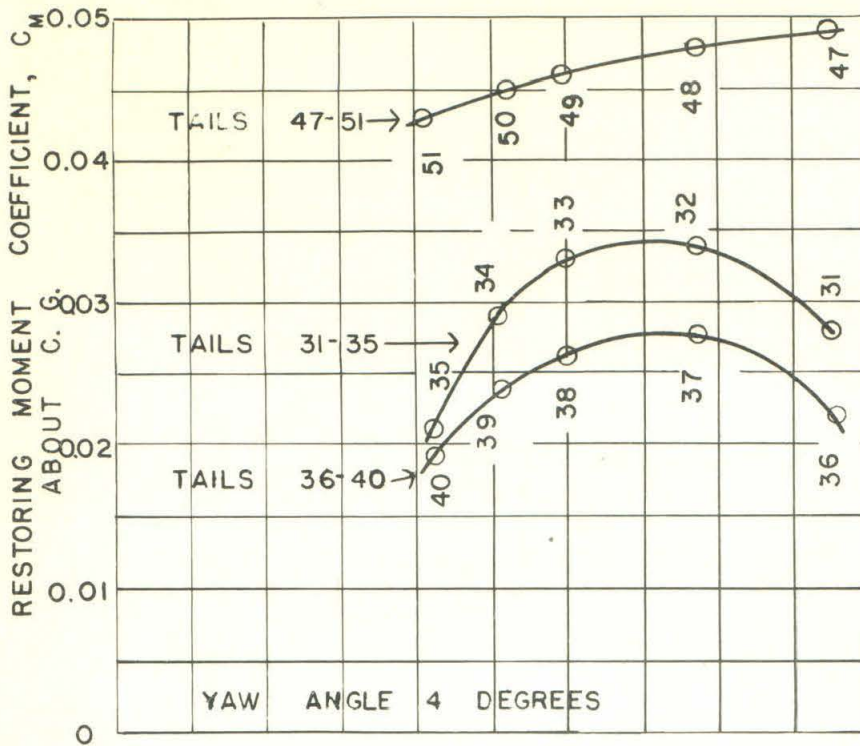
## 4. EFFECT OF SHROUD LENGTH

Figure 15 shows the effect of shortening the shroud length on the drag, the moment coefficient, and the center-of-pressure eccentricity for three series of tails. The shroud length was changed by cutting short lengths from the after end, thus shortening the overall length of the projectile. The curves indicate that a shroud length of about 80% of the shroud diameter (about 1-7/8 inches) is most effective in giving stability for Tails 31-35 and 36-40. For tails 47-51 this shroud length gives nearly as good stability as the longest shroud. The drag is not greatly influenced by the shroud length of Tails Nos. 31-35 and 36-40. For Tails Nos. 47-51, however, a shroud length 80% of the diameter shows about 25% lower drag than a shroud of the full diameter. The curves on Figure 14 for Tails Nos. 31 to 35 are not comparable to the curves for these tails which are shown on Figure 11 of Report No. ND-11.4 (Section No. 6.4-sr-207-920) for two reasons: first, a consistent computation error was discovered in further checking of Figure 11 of Report ND-11.4; and, second, as mentioned above, a different length is used in calculating the curves of Figure 14.

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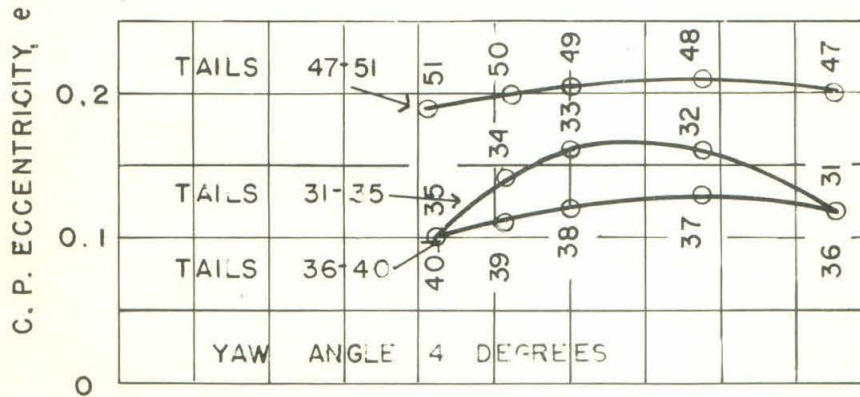


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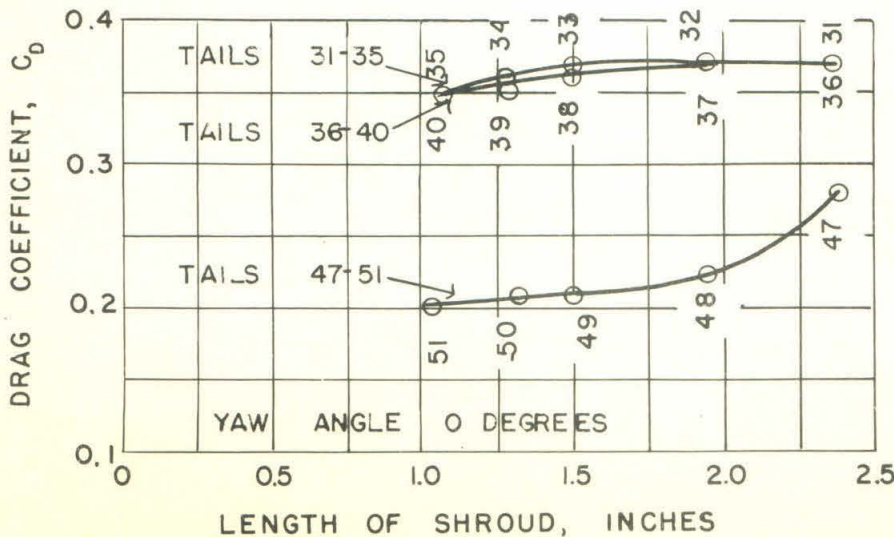
NO. 31-35 SERIES  
(RUNS 39, 42, 46, 47, 48, 49)

NO. 36-40 SERIES  
(RUNS 52, 57, 58, 59, 72, 75, 77, 78, 83)



NO. 47-51 SERIES  
(RUNS 91, 96, 97, 98, 107)

EFFECT OF  
SHROUD LENGTH  
ON  $C_D$ ,  $C_M$ , &  $e$   
FOR THREE DIFFERENT  
SHROUD RING  
TAILS



HIGH SPEED WATER TUNNEL  
AT THE  
CALIFORNIA INSTITUTE  
OF TECHNOLOGY



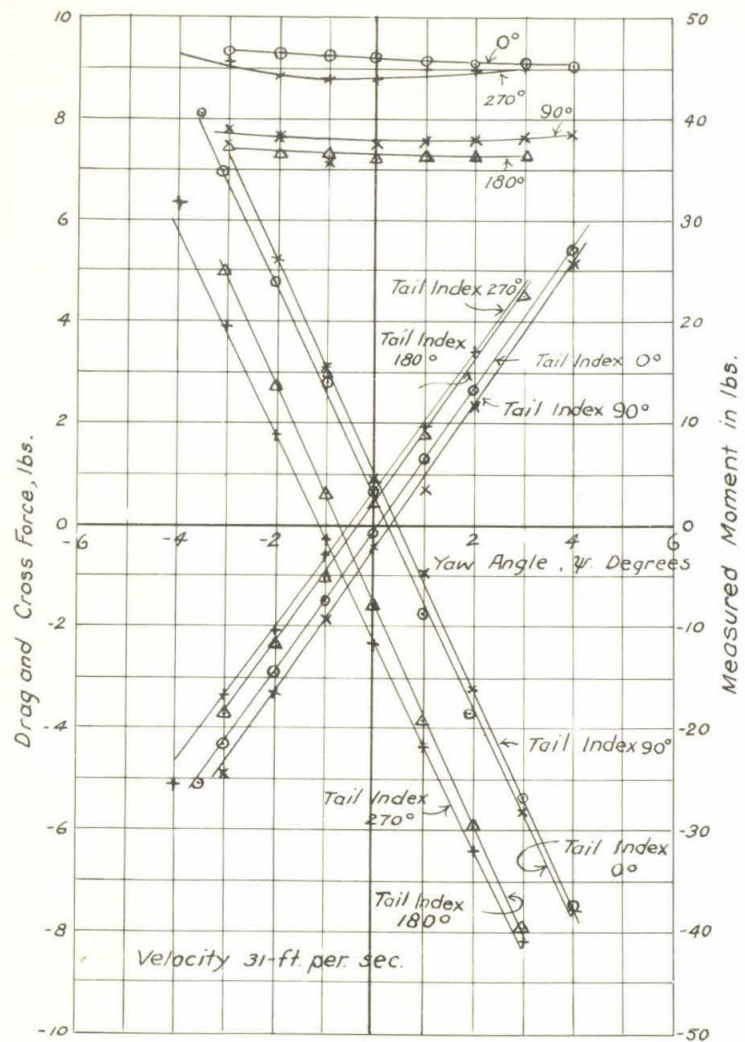
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5. EFFECT OF ASYMMETRY

Tails Nos. 58 and 59 both showed evidence of considerable asymmetry in construction. In the Water Tunnel the effect of asymmetry is to vary the force measurements as the tail is rotated relative to the plane of yaw.

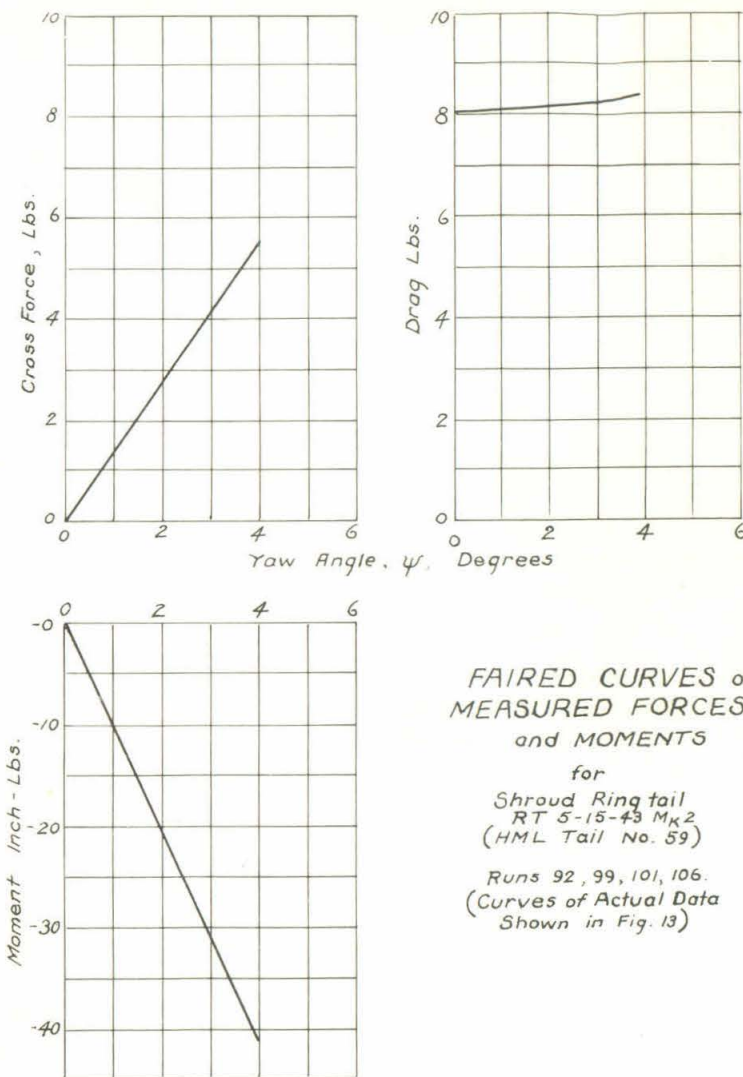
Figure 16 is a composite plot of the actual observed drag and cross force in pounds, and of the observed moment in inch-pounds for the model with Tail No. 59 at tail rotations of 0, 90, 180, and 270 degrees from an arbitrarily chosen index point. It is to be noted that for each tail position the slopes of the cross force and moment curves are practically constant. The cross force and moment curves of Figure 17 were obtained by shifting the cross force and moment curves of Figure 16 up or down so as to pass through zero, replotting the observed points with this correction and fairing the final curve through all the points so plotted. The drag is taken to be the average of the drag forces measured at the different tail rotation angles. The coefficients given in the tabulation for Tail No. 59 were calculated from the faired curves of Figure 17.

Figure 17 may be said to represent the characteristics of the rocket with a tail of the same design as Tail No. 59, but without asymmetry in construction, or the average characteristics of a large number of tails with variations in manufacture which introduce asymmetry.



EFFECT of ASSYMETRY on  
MEASURED FORCES and MOMENTS  
for Shroud Ring Tail RT 5-15-43 Mk 2  
(HML Tail No. 59) Rotated About Projectile Axis  
Runs 92, 99, 101, 106 CIT-HML  
DRG-ND 11-1682 L

Fig. 16



FAIRED CURVES of  
MEASURED FORCES  
and MOMENTS

for  
Shroud Ring tail  
RT 5-15-43 Mk 2  
(HML Tail No. 59)

Runs 92, 99, 101, 106.  
(Curves of Actual Data  
Shown in Fig. 13)

California Institute of Technology High Speed Water Tunnel  
Sheet No ND-11-1681 L

Fig. 17

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## 6. STUDIES IN POLARIZED LIGHT FLUME

Flow patterns about the models, particularly about the tails, were observed in the Polarized Light Flume. The fluid in the flume has asymmetrical physical and optical properties which permit observation of the flow lines when viewed through polarizing plates. The velocities in the flume are below the range of the Water Tunnel experiments and the pattern can be considered only qualitative.

Figures 18 to 29 inclusive show the flow lines as drawn from observation in the Polarized Light Flume.

FIGURE 18

TAIL No. 59  
NOSE No. 8  
ZERO YAW

FIGURE 19

TAIL No. 59  
NOSE No. 8  
4 DEGREES YAW

FIGURE 20

DETAIL OF  
TAIL No. 59  
ZERO YAW

FIGURE 21

DETAIL OF  
TAIL No. 59  
4 DEGREES YAW

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Figures 18 and 19 show the flow patterns observed in the rocket with the RT 5-15-43 Mk 2 Tail (Tail No. 59). Figures 20 and 21 show in more detail the flow pattern past the tail. Considerable eddying is noticeable aft of the second nozzle step and aft of the end of the nozzle. The flow pattern around the nose is not affected by the tail, and in the remaining flow pattern photographs, the nose is not shown.

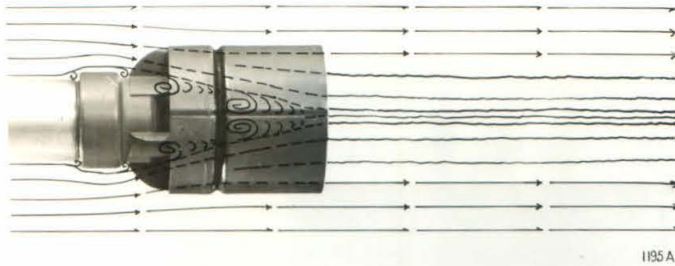


FIGURE 22  
DETAIL OF  
TAIL No. 58  
ZERO YAW

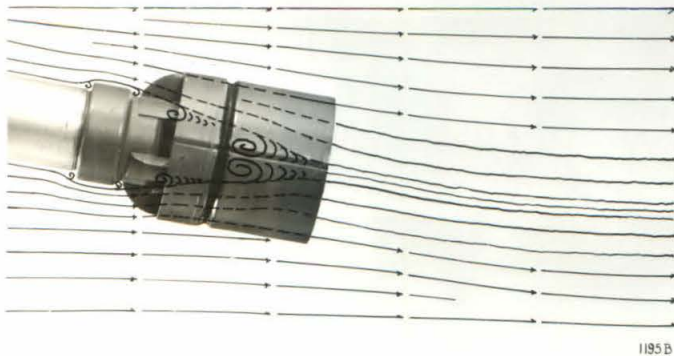


FIGURE 23.  
DETAIL OF  
TAIL No. 58  
4 DEGREES YAW

In Figures 22 and 23, Tail No. 58, considerable disturbance is indicated as the flow passes over the after part of the flanges which attach the fins to the nozzle. This disturbance is in addition to the disturbance at the nozzle steps and aft of the nozzle tip and may serve to explain the higher drag of the rocket with this tail.

Also, comparing Figures 22 and 23 with Figures 20 and 21, it appears that in both the straight and yawed positions more fluid is drawn through Tail No. 59 than through Tail No. 58. This is because the forward edge of the shroud is further aft relative to the nozzle for Tail No. 59 than for Tail No. 58, thus leaving a larger passage for the fluid to enter. Referring back to the tabulation, it is to be noted that the restoring moment is considerably larger for Tail No. 59 than for Tail No. 58.

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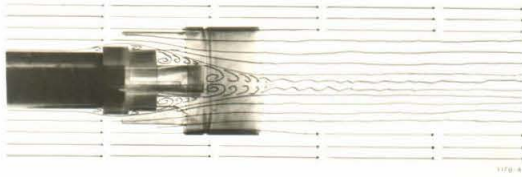


FIGURE 24  
TAIL NO. 33, ZERO YAW

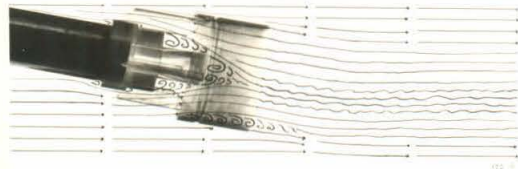


FIGURE 25  
TAIL NO. 33, 10 DEGREES YAW

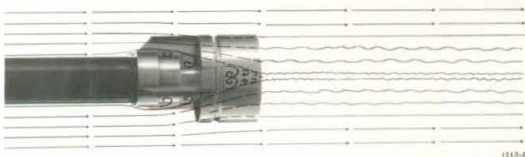


FIGURE 26  
TAIL NO. 38, ZERO YAW

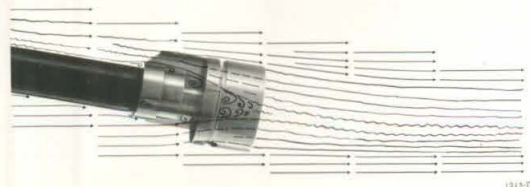


FIGURE 27  
TAIL NO. 38, 10 DEGREES YAW

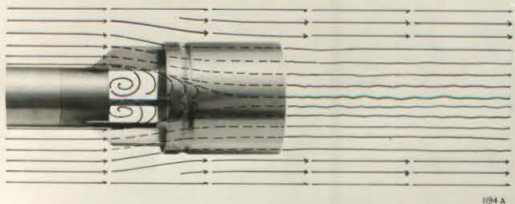


FIGURE 28  
TAIL NO. 47, ZERO YAW

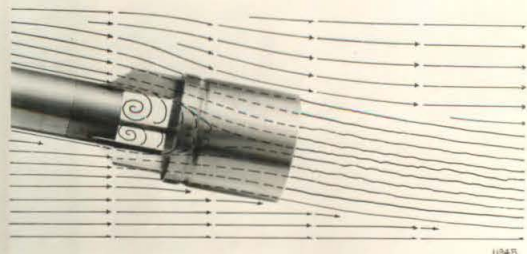


FIGURE 29  
TAIL NO. 47, 10 DEGREES YAW

The flow patterns for the tail mounted directly on the boom without nozzle are shown in Figures 28 and 29. Comparing them with Figures 24 to 27, which show flow lines past the stepped nozzle, indicates considerably less total eddying in the wake of the boom without the nozzle. The decrease in magnitude of the eddies appears to be correlated with decreased drag.

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7. TUNNEL INSTALLATION AND DESCRIPTION OF FORCES MEASURED

The tests were conducted in the 14" diameter working section of the High Speed Water Tunnel at the California Institute of Technology. (1) Figure 30 shows a projectile installed in the tunnel. In order to reduce the drag tare to a minimum, the rigid supporting spindle is protected from the flow by the streamline shielding shown in the figure. This shielding, which projects to within a few thousandths of an inch of the projectile, is held to a small size in order to reduce interference effects.

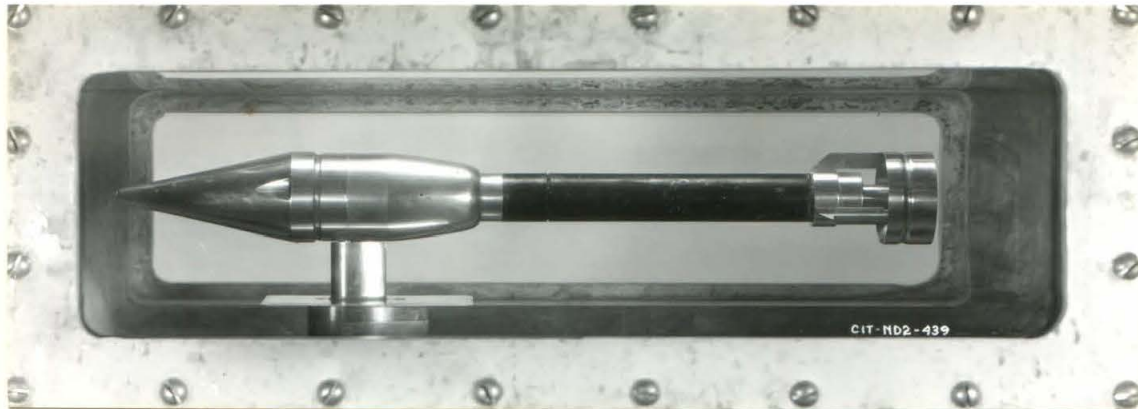


FIGURE 30

ROCKET MOUNTED IN WATER TUNNEL

NOSE NO. 8 RING TAIL NO. 35

The forces exerted by the flow on the model can be resolved, in general, into a drag force parallel to the flow, a cross force normal to the flow, and a moment or torque acting about the point of support. These are the forces measured during the tests. The moment exists only if the model is not supported at the point of application of the resultant of all the hydrodynamic forces. It is clear that the magnitude and sense of the measured moment will change if the point of support is shifted along the body.

The data presented in this report have not been corrected for tare or interference of the model support. However, the results are believed to be close to the correct values. Similar tunnel tests of streamlined projectiles have given data that agree closely with those obtained from full scale field tests. The Water Tunnel test results are applicable in air as well as in water for velocities below that of sound. For air velocities in the neighborhood or above that of sound, the results will not apply.

(1) Figures refer to references listed at the end of this report.



HYDRAULIC MACHINERY LABORATORY  
CALIFORNIA INSTITUTE OF TECHNOLOGY  
PASADENA, CALIFORNIA

MODEL TAIL #59  
FOR 236 ROCKET PROJECTILE

DR HCY - 8/12/43

SCALE

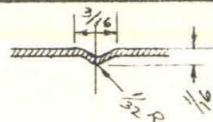
CH CRA - 8/13/43

AP

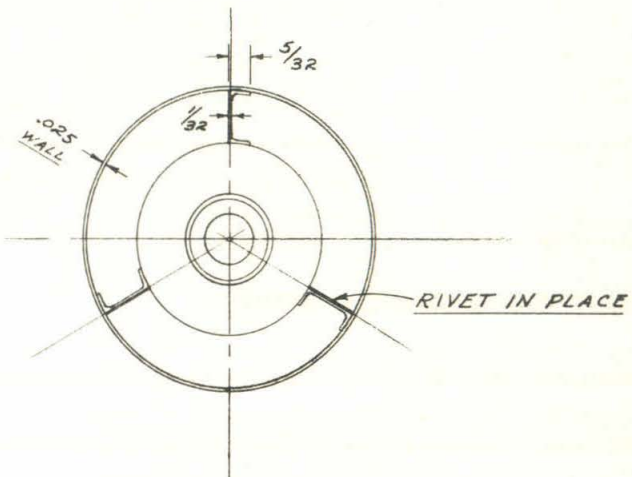
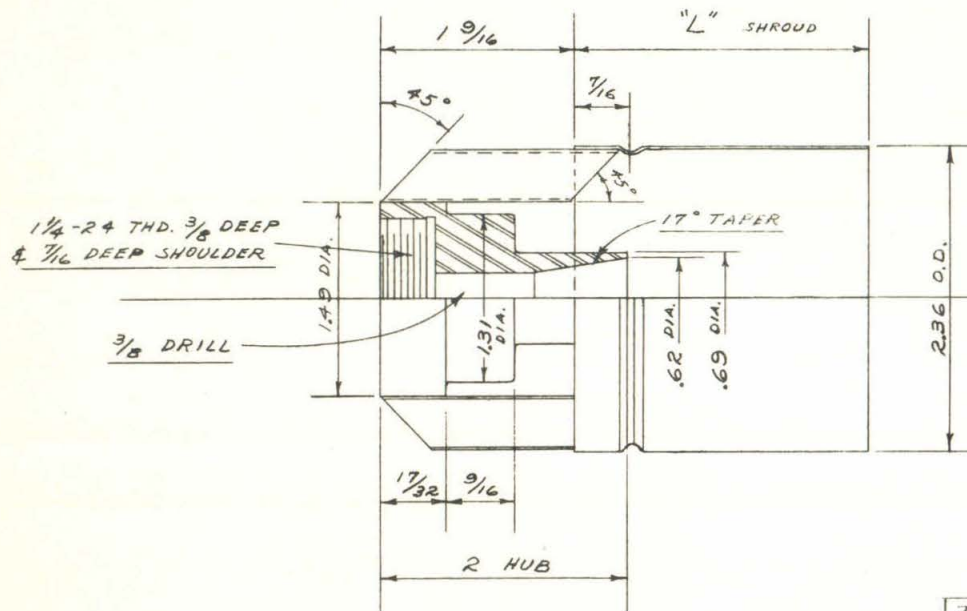
ND-483-U

FIGURE 31





GROOVE DTL.  
DOUBLE SIZE



TAIL #	"L"
31	2 3/8
32	1 13/16
33	1 1/2
34	1 9/32
35	1 1/16

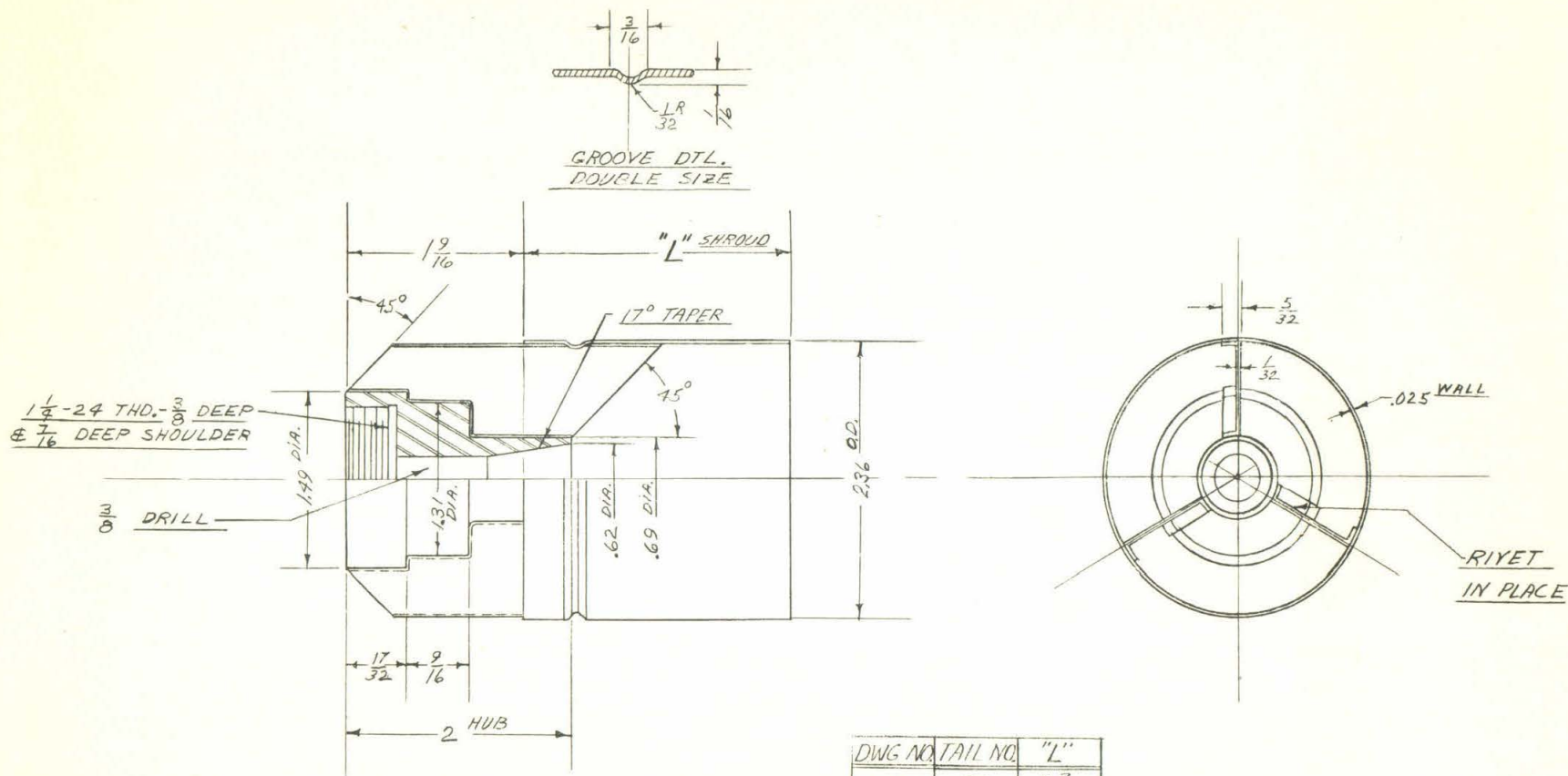
MAT'L. ~ BRASS

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HYDRAULIC MACHINERY LABORATORY CALIFORNIA INSTITUTE OF TECHNOLOGY PASADENA, CALIFORNIA	
MODEL TAIL #31 thru 35	
DR CRA 6-4-43	SCALE ~
CH	ND-406 -U
AP JWD	

FIGURE 33





LEAVE SQUARE EDGES  
FILLETS TO HAVE .03R

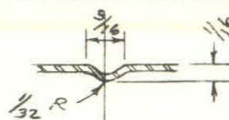
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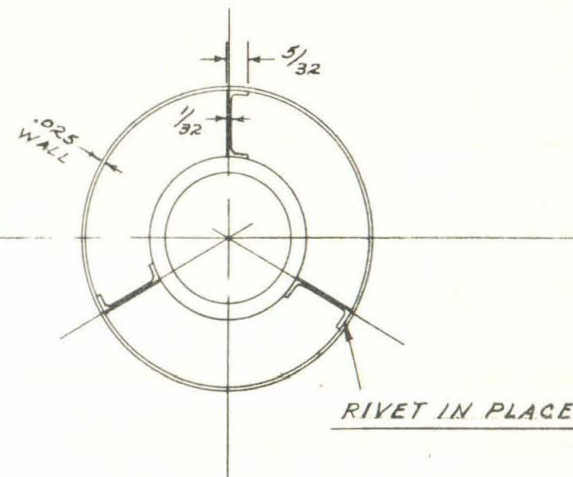
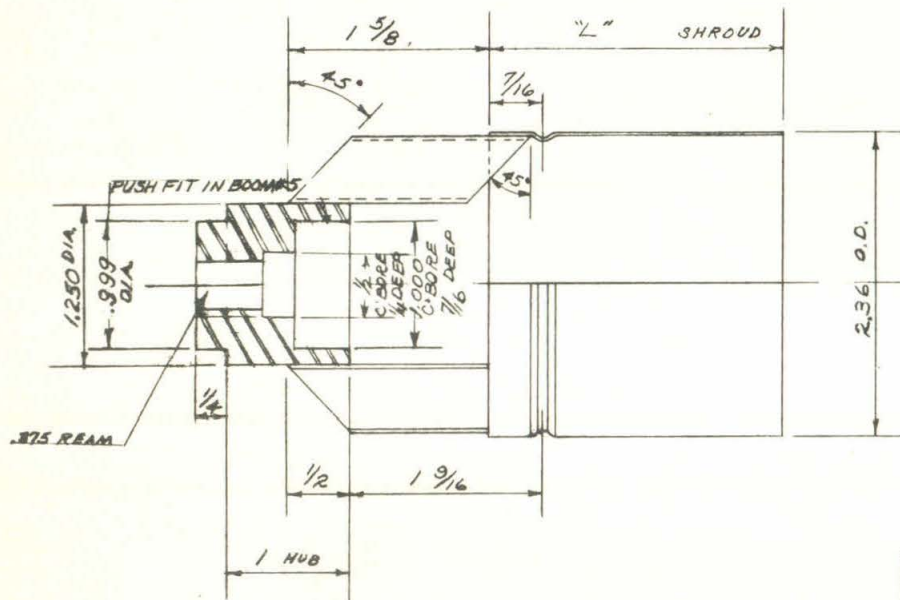
HYDRAULIC MACHINERY LABORATORY  
CALIFORNIA INSTITUTE OF TECHNOLOGY  
PASADENA, CALIFORNIA

MODEL TAIL  
#36 THRU 40

DR JWC 6-8-43	SCALE
CH CRA 6-8-43	ND-417
AP JWD -	421 -U



GROOVE DTL.  
DOUBLE SIZE



DWG NO	TAIL NO	"L"
ND 438	47	2 7/8
ND 439	48	1 15/16
ND 440	49	1 1/2
ND 441	50	1 9/32
ND 442	51	1 1/32

LEAVE SQUARE EDGES

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MODEL TAIL #47 FOR 2.36 DIA. ROCKET PROJECTILE	
DR CRA 6/24/43	SCALE
CH HB	ND-438 -U
AP	

FIGURE 35

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REFERENCES:

- (1) For complete description see the following report on file in the office of Section 6.1, NDRC, "The High Speed Water Tunnel at the California Institute of Technology", by R. T. Knapp, V.A. Vanoni, and J. W. Daily, June 29, 1942.





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THE HIGH SPEED WATER TUNNEL  
AT THE  
CALIFORNIA INSTITUTE OF TECHNOLOGY

## APPENDIX A

## DEFINITIONS

## YAW ANGLE

The angle which the axis of the model makes with the direction of flow. Looking down on the model, yaw angles in a counter-clockwise direction are negative (-) and in a clockwise direction, positive (+).

## MOMENTS

Moments tending to rotate the model in a counter-clockwise direction (when looking down on the model) are negative (-), and those causing clockwise rotation, positive (+).

In accordance with this sign convention a moment has a destabilizing effect when it has the same sign as the yaw angle.

In all model tests the moment is measured about the point of support.

Moments about the center of gravity have the symbol,  $M_{cg}$ .

## DRAG

The force, in pounds, exerted on the model parallel with the direction of flow.

## CROSS FORCE

The force, in pounds, exerted on the model normal to the direction of flow. A positive cross force is defined as one acting in the same direction as the displacement of the projectile nose for a positive yaw.

## NORMAL COMPONENT

The sum of the components of the drag and cross force acting normal to the axis of the model. The value of the normal component is given by the following:

$$N = (D \sin \psi + C \cos \psi)$$

in which

$N$  = Normal component in lbs

$D$  = Drag in lbs

$C$  = Cross force in lbs

$\psi$  = Yaw angle in degrees

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## CENTER OF PRESSURE

The point in the axis of the model at which the resultant of all forces acting on the model is applied. This has the symbol (CP).

## CENTER-OF-PRESSURE ECCENTRICITY

The distance between the center of pressure (CP) and the center of gravity (CG) expressed as a decimal fraction of the length (L) of the model. The center-of-pressure eccentricity (e) is derived as follows:

$$e = \frac{(L_{cg} - L_{cp})}{L} = \frac{1}{L} \frac{M_{cg}}{N}$$

in which

e = Center-of-pressure eccentricity

L = Length of model in feet

$L_{cg}$  = Distance from nose of projectile to CG in feet

$L_{cp}$  = Distance from nose of projectile to CP in feet

## COEFFICIENTS

The three force coefficients used are derived as follows:

$$\text{Drag Coefficient, } C_D = \frac{D}{\rho \frac{V^2}{2} A_D}$$

$$\text{Cross force coefficient, } C_C = \frac{C}{\rho \frac{V^2}{2} A_D}$$

$$\text{Moment Coefficient, } C_M = \frac{M}{\rho \frac{V^2}{2} A_D L}$$

in which

D = Measured drag force in lbs

C = Measured cross force in lbs

$\rho$  = Density of the fluid in slugs/cu ft

w = Specific weight of the fluid in lbs/cu ft

g = Acceleration of gravity in ft/sec<sup>2</sup>

$A_D$  = Area in sq ft of a cross section at the cylindrical portion of the projectile taken normal to the geometric axis of the projectile

V = Mean relative velocity between the water and the projectile in ft/sec



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M = moment in foot-lbs measured about any particular point on the geometric axis of the projectile

L = Overall length of the projectile in feet

## GENERAL DISCUSSION

The curves of force and moment coefficients and of center-of pressure distance plotted as functions of the yaw angle are useful for a discussion of the stability of projectiles. Since these tunnel tests are made under steady flow conditions, the results will only indicate the tendency of the projectile to return to or move away from the equilibrium position after a disturbance. Adopting aerodynamic usage, a projectile is said to be "statically" stable if it tends to return to equilibrium when disturbed. In the discussion of static stability the actual motion following the perturbation is not considered at all. In fact, a projectile may oscillate about the equilibrium position without ever remaining in it. In this case the projectile would be statically stable even though "dynamically" unstable. For a complete discussion of the mode of motion to be expected following a perturbation, the "dynamic" stability, additional information is necessary.

The condition for equilibrium is satisfied if  $C_M$ , calculated about the CG is equal to zero. In general, for projectiles with axial symmetry the moment is zero at  $\psi = 0^\circ$ , so that for equilibrium the projectile is oriented with its axis parallel to the direction of motion. If the projectile is rotated from the equilibrium position so as to give it a positive yaw angle, it is necessary that it have a negative moment coefficient, according to the sign convention adopted, in order that it be statically stable. Thus, a negative slope of the curve,  $C_M$ , vs.  $\psi$  corresponds to static stability, and a positive slope corresponds to instability. The degree of stability or instability is indicated by the magnitude of the slope. The same conclusions are obtained by interpreting the center-of-pressure curves. For symmetrical projectiles, if the center of pressure falls behind the center of gravity, a restoring moment exists and the projectile is statically stable. If the CP lies ahead of the CG, the moment is non-restoring and the projectile is statically unstable. The degree of stability or instability is indicated by the distance between the center of gravity and center of pressure.

